Optimization of the Injector Fuel Distribution For Stable, Low Emissions Combustion In Lean Premixed Gas Turbine Combustors

Kwanwoo Kim
Byeong-Jun Lee
Jong Guen Lee
Dom Santavicca

Penn State University

Turbine Power Systems Conference
Galveston, Texas

February 25-27, 2002

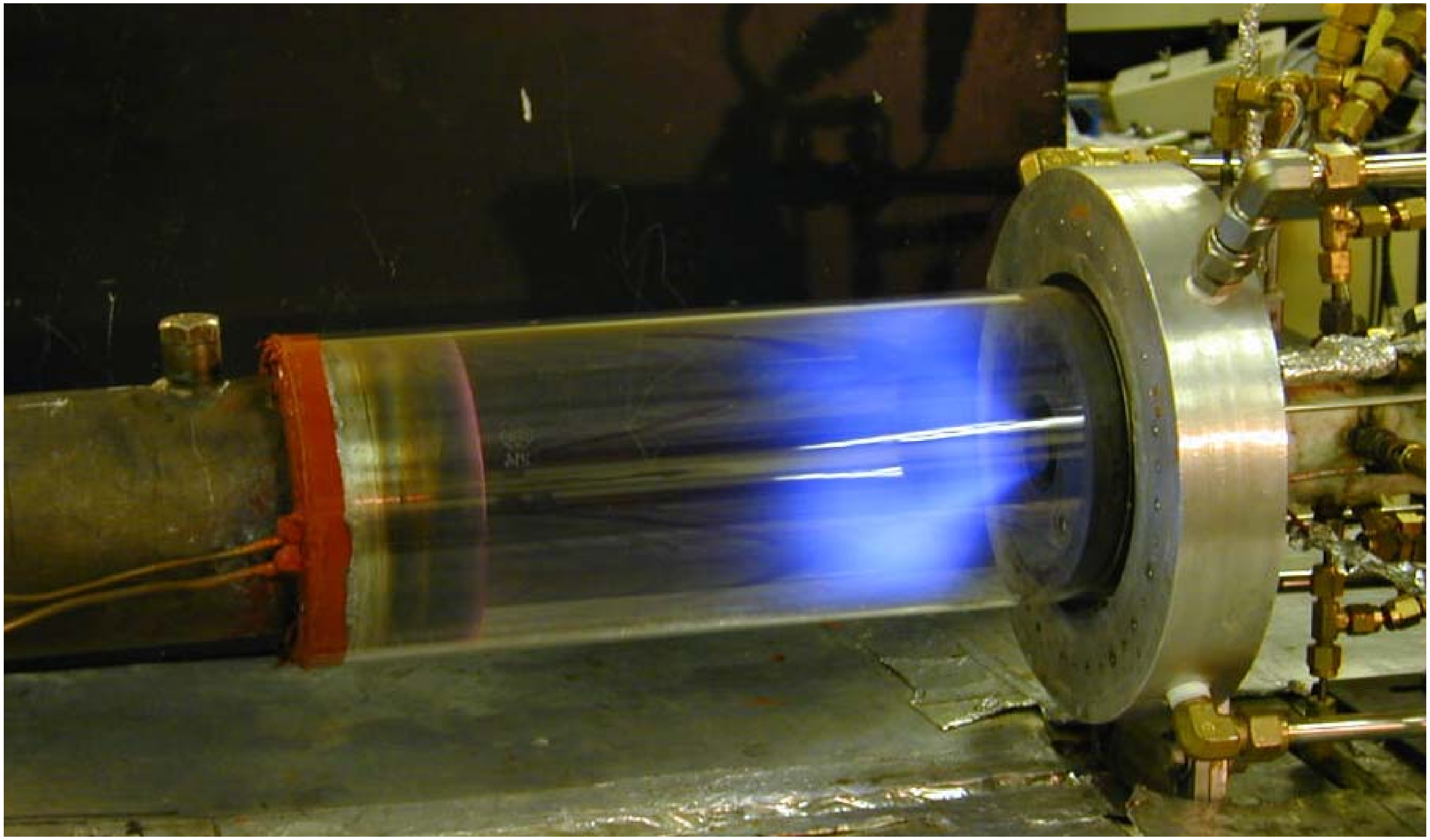
- **Can the fuel distribution be used to control combustion dynamics in lean premixed combustors?** **YES**

Pilot Flames (spatial) ⟷ Modulated Main/Secondary Injection (temporal and spatial)

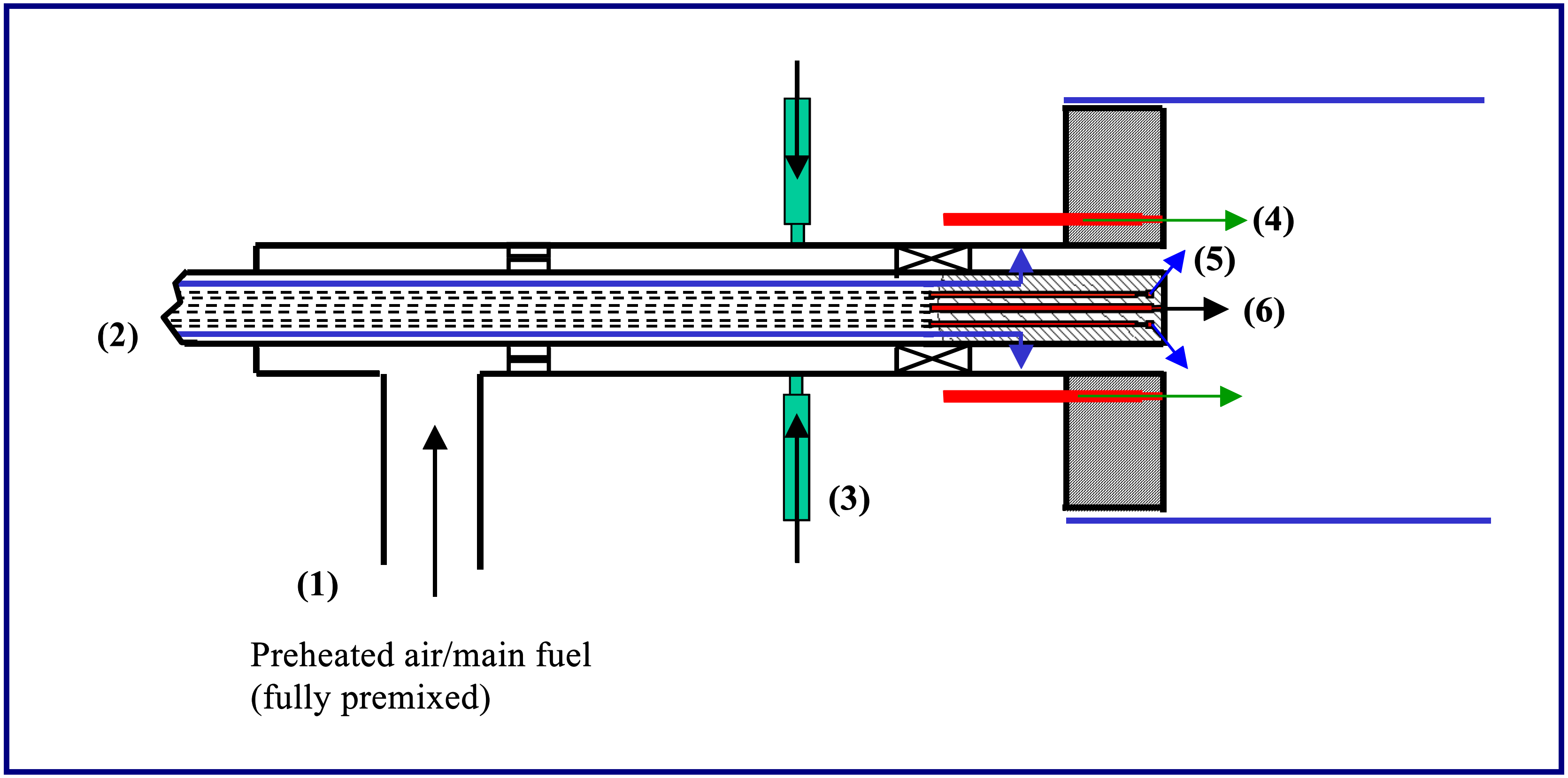
- **Can we develop a comprehensive strategy for all instabilities?**

- **What is the impact on NO_x emissions?**

Optically Accessible Combustor



Fuel Distribution Control



To Be Studied

- **the effect of the inlet fuel distribution**
  - **spatial and temporal**
- **the effect of targeted injection**
  - **steady and modulated**

Results to Date

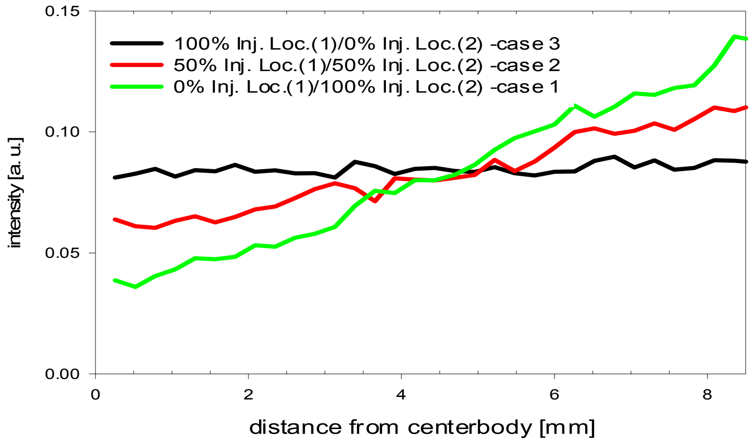
- **effect of spatial fuel distribution**
- **effect of temporal fuel distribution**
  - **sub-harmonic injection**
  - **transverse fuel injection**

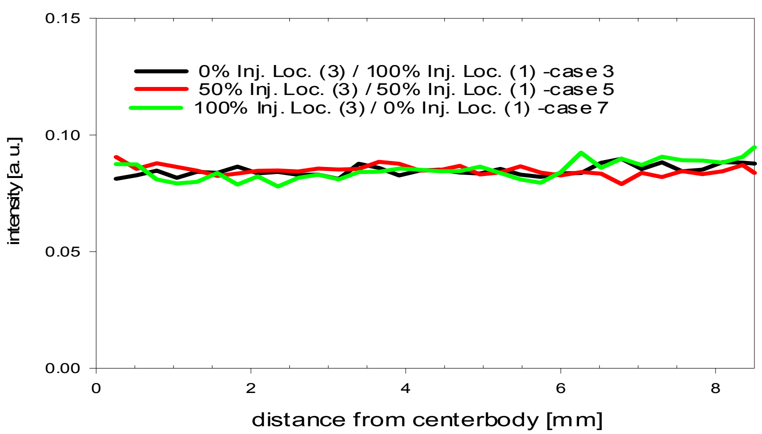
Effect of Spatial Fuel Distribution: Test Conditions

pressure	1 atm and 2.5 atm
inlet temperature	300°, 350°C, 400°C and 450°C
inlet velocity	3.5, 5.0, 6.5 and 8.0 m/s
swirl	30° and 60°
equivalence ratio	LBO to 0.8
fuel	natural gas
power	40 - 180 kW
fuel distribution	see next figure

Fuel Distribution Measurements (PLIF)

Fuel Distribution	Injection Location (1)	Injection Location (2)	Injection Location (3)
Case 1	0%	100%	0%
Case 2	50%	50%	0%
Case 3	100%	0%	0%
Case 4	75%	0%	25%
Case 5	50%	0%	50%
Case 6	25%	0%	75%
Case 7	0%	0%	100%





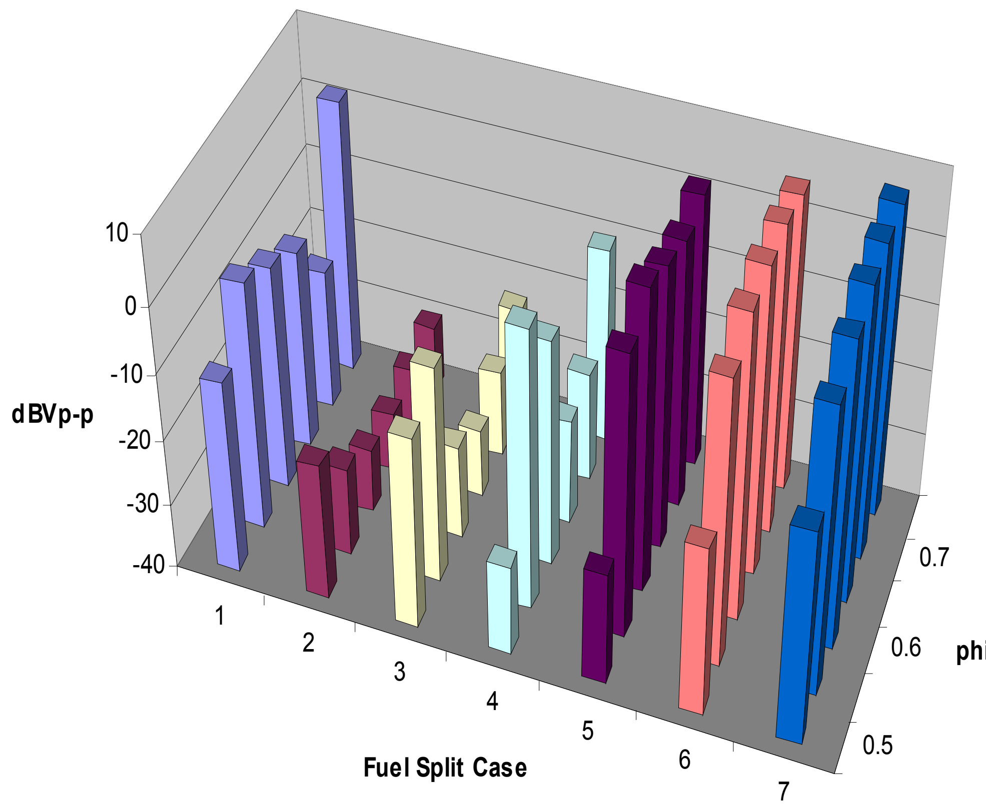
PENNSTATE
1855

Stability Map: Fuel Distribution vs. Equivalence Ratio

Inlet Velocity = 5 m/s

Swirl Angle = 30°

Inlet Temperature = 350°C

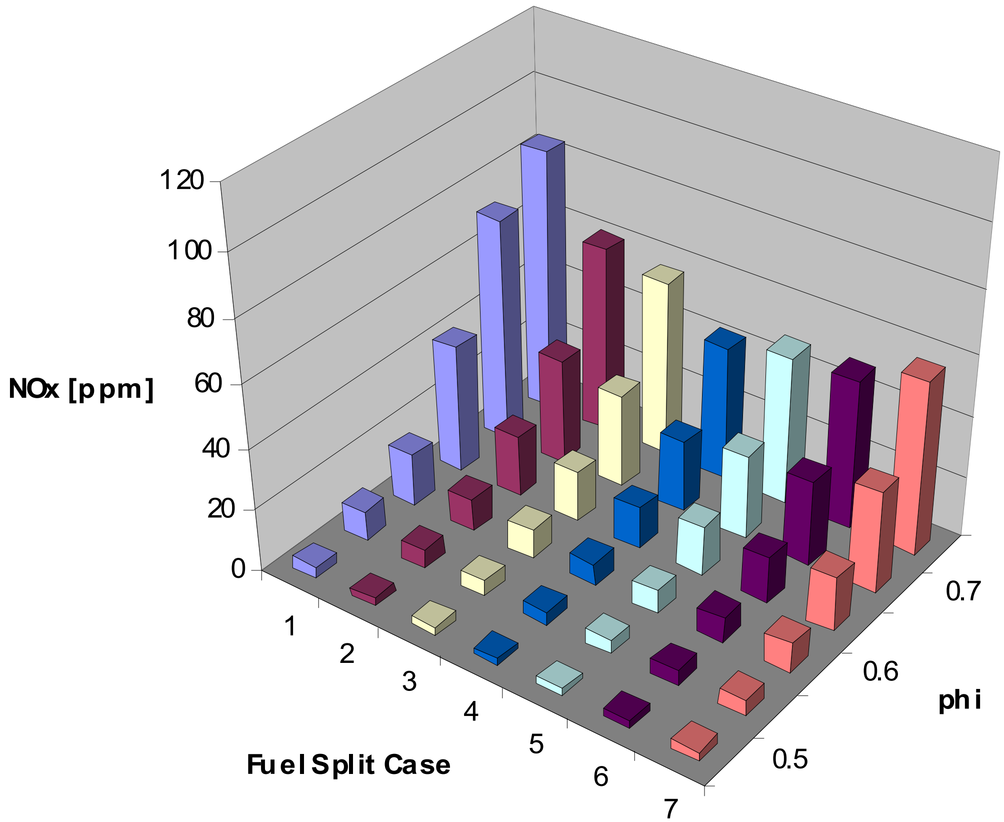


NO$_x$ Map: Fuel Distribution vs. Equivalence Ratio

Inlet Velocity = 5 m/s

Swirl Angle = 30°

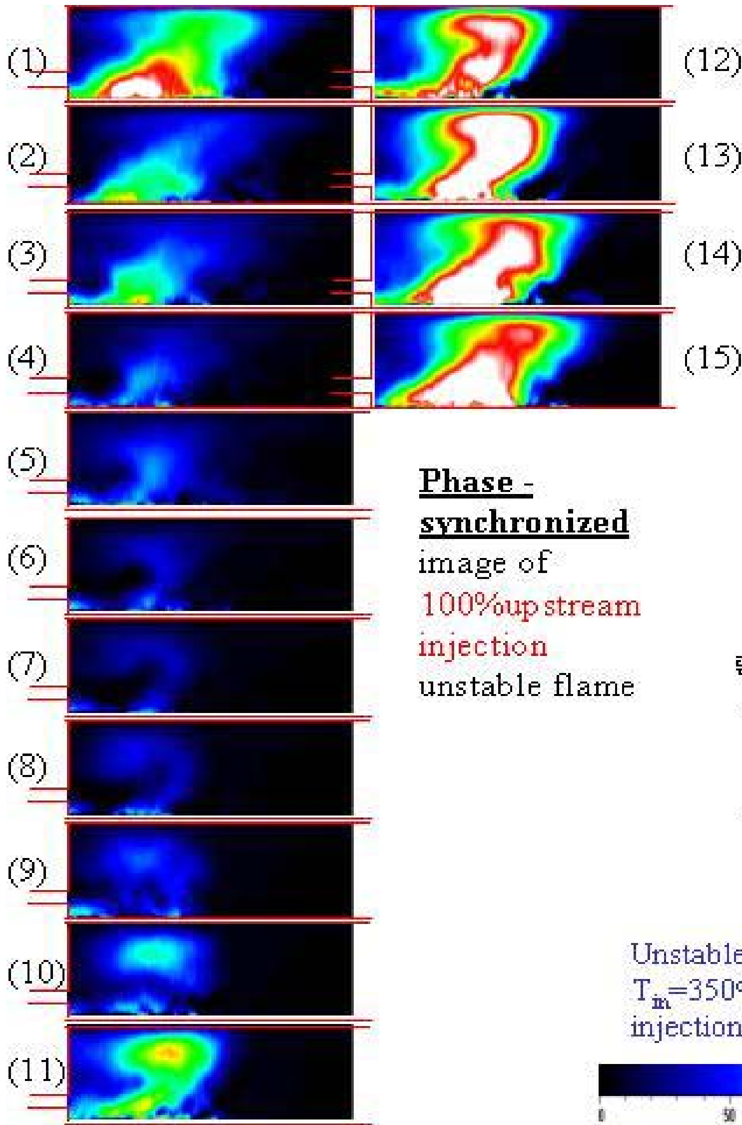
Inlet Temperature = 350°C



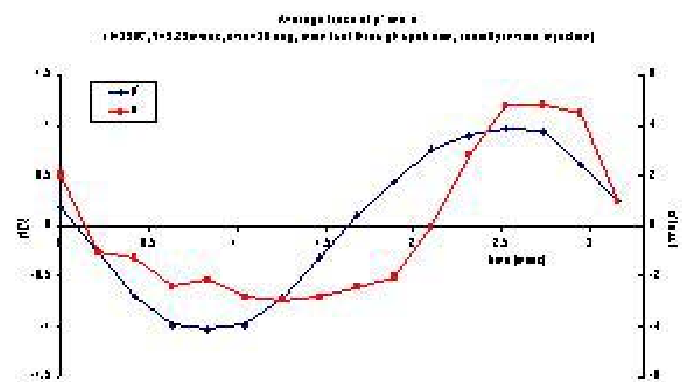
- Our goal is to be able to determine the fuel distribution required to achieve stable combustion over the entire operating range of any given lean premixed combustor.

- This requires an understanding of how the fuel distribution affects combustion stability in lean premixed combustors.

- An improved understanding of these effects can be obtained by studying the change in flame structure that results from a given change in the fuel distribution.

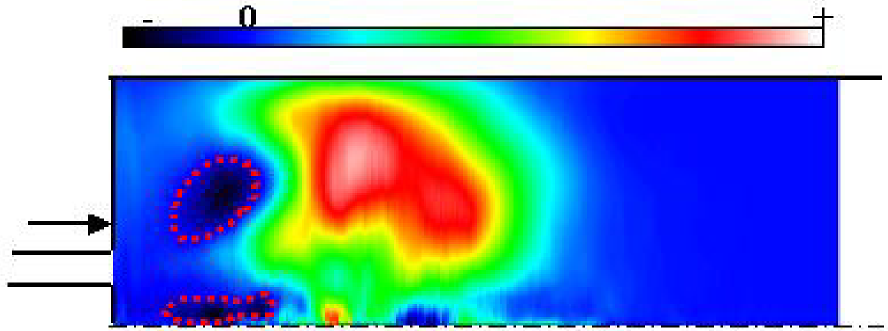


Phase - synchronized image of 100%upstream injection unstable flame

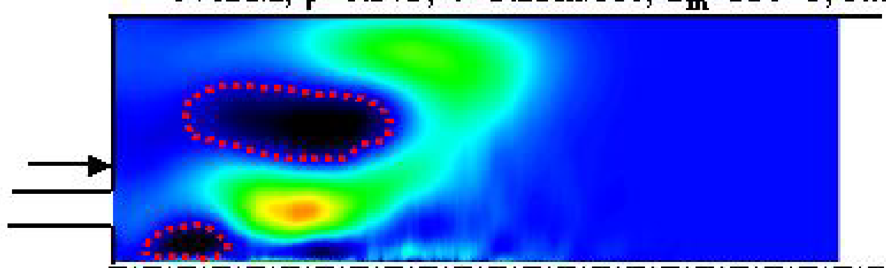


Unstable flame images over one instability cycle T_{in}=350°C, V=5.25m/sec, 30°swirl, 100% upstream injection, ϕ=0.575

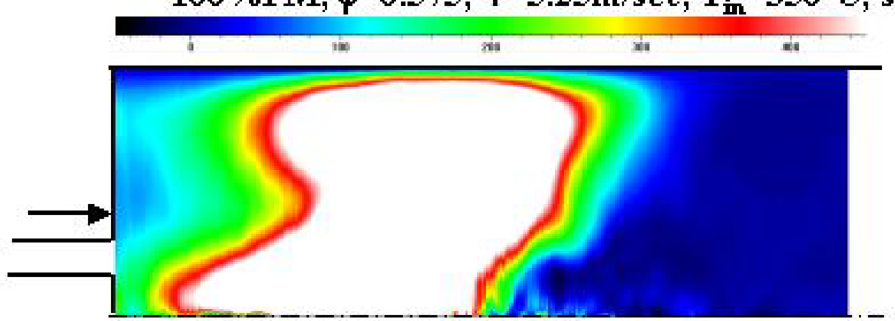
Local Rayleigh index distribution three fuel distributions



0%PM, ϕ=0.575, V=5.25m/sec, T_{in}=350°C, swirl=30°

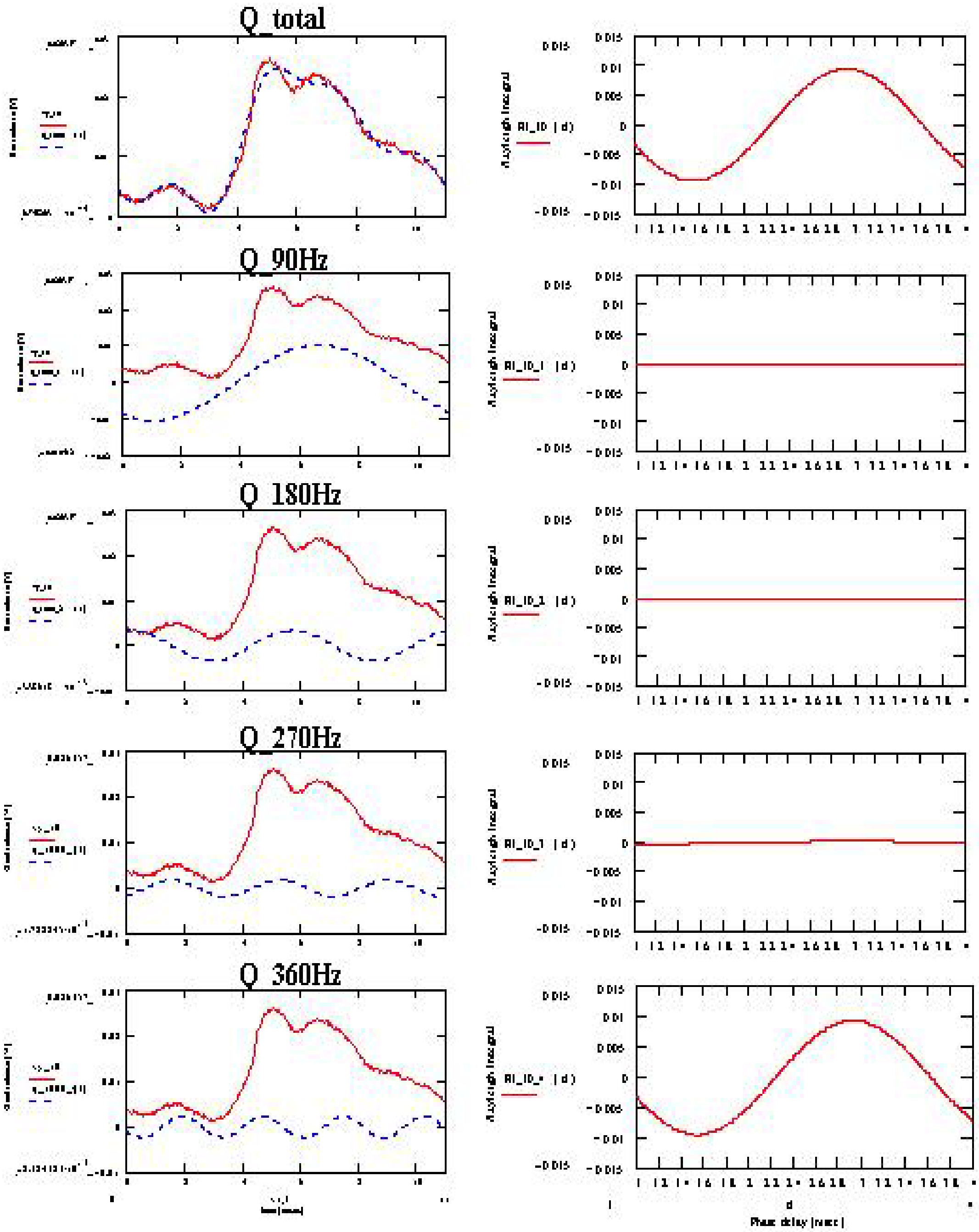


100%PM, ϕ=0.575, V=5.25m/sec, T_{in}=350°C, swirl=30°

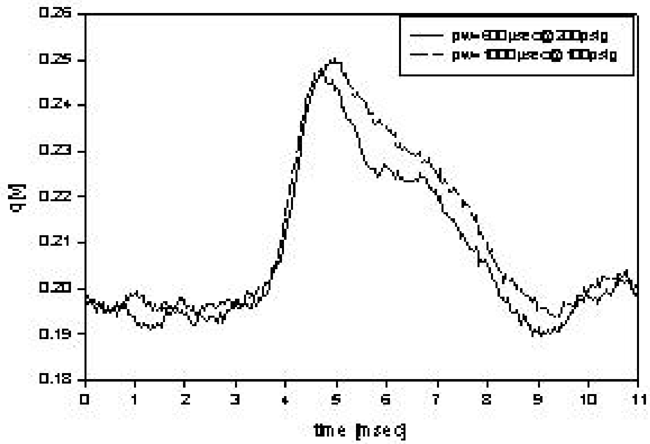


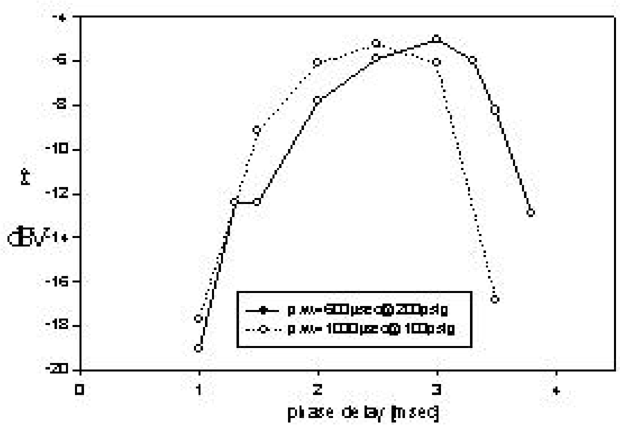
100% Upstream injection, ϕ=0.575, V=5.25m/sec, T_{in}=350°C, swirl=30°

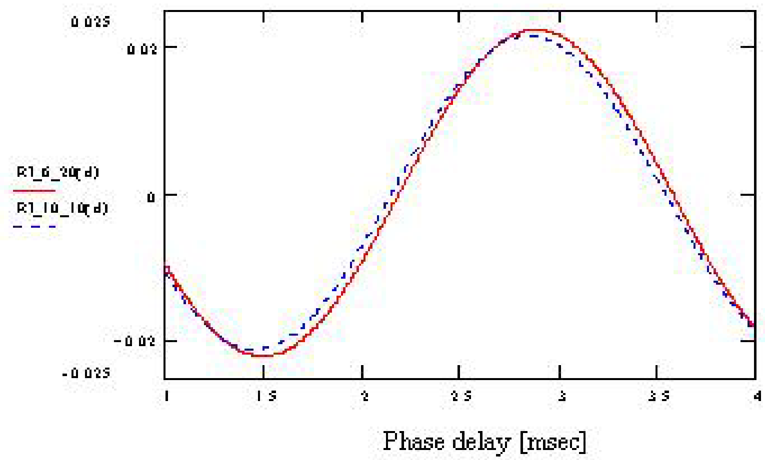
Subharmonic Injection



finj=90Hz, dump plane injection
(pulse width & P_{inj} combinations with similar control effectiveness
using different amount of fuel)







$$\frac{\dot{m}_{inj}(600\ \mu\text{sec},200\text{psig})}{\dot{m}_{inj}(1000\ \mu\text{sec},100\text{psig})} = \frac{5}{8}$$

PENNSTATE

Future Work

- → determine the effect of inlet spatial fuel distribution on stability and emissions over the entire operating range of the combustor.
- → determine the effect of steady targeted fuel injection on stability and emissions over the entire operating range of the combustor.
- → use chemiluminescence flame structure imaging to develop a mechanistic explanation of the effect of the inlet fuel distribution and steady targeted fuel injection on stability.

Future Work (continued)

→ formulate a methodology for using inlet fuel distribution and targeted injection to control instabilities in lean premixed combustors.

→ apply this methodology to one or more industrial injectors, e.g., Solar's Centaur 50 injector.

→ continue to investigate the use of subharmonic injection for active control of combustion dynamics using both main and secondary fuel modulation.